

THE ROAD AND THE ENVIRONMENT, A MARRIAGE OF CONVENIENCE: THICK POROUS PAVEMENTS

Jean-Pierre Christory
Laboratoire Régional de
l'Ouest Parisien
(FRANCE)

Gilles Pipien
Direction
Départementale de
l'Équipement du Rhône
(FRANCE)

Bernard Soudieu
Mairie de Paris -
Direction de la Voirie
(FRANCE)

Jean Chauchot
Syndicat des
Entrepreneurs de
Chaussées en Béton et
Équipements annexes
(FRANCE)

The past half-century has witnessed continuous extension of urban areas, and growing attention is being given to environmental issues especially in industrialized countries. In certain critical situations within very large conurbations, the construction and improvement of vital road facilities in order to deal with traffic congestion will be pursued effectively only if highway professionals are able to come up with user- and environment-oriented technological approaches in which quality workmanship is a primary prerequisite.

While a few years ago roads were still required to fulfill a "traffic" function durably and reliably, the tendency today is to demand much more, requiring them to perform, in addition to their basic "traffic" mission, an active function with regard to noise control, with regard to hydrological risks in municipal rainwater drainage, as well as with regard to pollution control, aesthetics, the behavior of users, and so on. (1) (2).

Porous materials were a major subject of work in France in the past 5 years, and after the first period of examination and testing on small structures, it was possible to validate the concept of porous, free-draining materials in the pavement structure and surfacing. The success achieved on the one hand by porous bituminous mixes and on the other by porous cement concretes in the sub-bases of concrete pavements has allowed significant progress in demystifying to a certain extent certain preconceived notions, such as "water and voids are the enemies of the road". Experimentation on reservoir structures (3) (4) (5), on low-noise structures (6) (7), and on anti-hydroplaning surfaces (8) made it possible, by the end of 1990, to outline the objectives, principles and fields of application of porous structures, as shown in the diagrams of Figures 1 and 2 (9).

This schematic representation shows that the peri-urban sector, an expanding sector within the urban fabric, is affected in a privileged manner by the broader range of application fields for porous structures, covering simultaneously all the reservoir, noise and hydroplaning objectives.

Research on porous structures and materials covered all types of pavements. However, porous cement concrete pavements were considered able to play a privileged role in certain fields of application, in view of their unique characteristics in terms of placement thicknesses, generally medium or high (> 15 cm) on the surface and the absence of post-compacting or variations in the internal texture as a result of rheological action, repeated loading, temperatures, etc. This paper thus endeavors to develop upon this aspect, showing the theoretical advantages of the porous concrete structure, the promising results obtained after field trials and the points with regard to which much work still remains.

MULTIFUNCTION POROUS STRUCTURES — THE ADVANTAGES OF POROUS CONCRETE.

Among the three basic objectives distinguished in the diagrams of Figures 1 and 2 — Reservoir, Hydroplaning, Noise — the present discussion will consider more particularly the NOISE objective. Let us however note that:

As concerns reservoir pavements, extensive experience has been acquired with porous foundation concretes, used in the design of modern heavy traffic pavements to provide the continuous drainage indispensable for the life of these structures (10).

Mention may be made of the bases and widening of the French Autoroute (freeway) A1 (Figures 3 and 4) (11), among the most heavily loaded facilities in France, or the porous concrete shoulder areas also used on facilities of this type.

Porous concretes in large widths are also used on the main runway of the Paris Charles de Gaulle Airport. The effectiveness and durability of porous concrete pavements in terms of drainage has been demonstrated and has led to an international consensus embodied in the PIARC Recommendation on the control of pumping and drainage in concrete pavements (12) (Figure 5).

The township of Paris is interested in this hydraulic aspect of porous cement concrete structures, and has instrumented the experimental section of the Avenue de la Porte de Vitry, which we shall look into in greater detail below (Figure 6).

As concerns hydroplaning, it was important for cement concrete pavements to be able to offer an alternative to porous bituminous mixes used on existing roadways. Within this objective of the use of bonded thin layers, it was necessary to address not only the question of the surface porosity of the porous concrete surfacing, but also the question of the bonding of this layer to the underlying material of the existing concrete pavement.

This double objective was achieved on the experimental site of the Rue Léon Bollée in Paris headed by the Directorate of Roads of the township of Paris (13).

This township, very sensitive to safety, comfort and environmental issues, undertook a major road development plan with the main concern of reducing disturbance to users.

This busy street (public transportation, residential buildings, hospital center) 11 meters wide was built with a California-type concrete slab structure with dimensions of 5m x 2.5m and a thickness of 0.2m. The thin porous cement concrete surfacing (5 to 6cm) placed over it had the following mix design:

6/10 porphyry aggregate	1500kg/m ³
0/4 Seine sand	150kg/m ³
CPA 55 cement	400kg/m ³
Silica fume based additive	30kg/m ³
Water	30l/m ³

This mix design was chosen after full-scale 24-hour erodability tests with a 15-ton truck: wheels turned on stopping and braking at 30km/h.

The essential construction points which accounted for the success of this project in terms of its objectives are the following (Figure 7).

- Very careful preparation of existing pavement: repair of joints, repair of some broken slabs; general peening
- Spreading of tack coat (slurry)
- Spreading with paver, with slight surface vibration
- Covering of fresh porous concrete with metallized aluminum polyethylene to insulate the porous concrete thermally (temperature gradient control mainly) and avoid surface drying.

The final result met the wishes of the customer entirely. Significant improvements were made in terms of comfort (smoothing of longitudinal profile by reducing short wavelength defects), safety (improvement in sideways force coefficient, especially in the direction opposite paver placement because of the flattening of aggregates on the surface). The hydroplaning function was very effectively fulfilled, with percolation rates of 0.91 cm/s. This porous pavement was of course subject to fouling by dust carried by rainwater after a certain time and, as in the case of porous materials used in urban areas, required preventive declogging operations with machines whose technical and economic efficiency have been and continue to be improved rapidly because of the very important stakes represented by the preventive maintenance of porous pavements and subsequently of multifunction porous pavements (examples of processes used in France: FRIMOKAR machine, RUGOR machine, among others.)

In addition to the usage qualities required for urban pavements, it is observed that in these porous concrete pavements there is no creep or rutting, no loss of porosity with time through post-compacting, hence the possibility of easier flushing by means of water under pressure and, finally, very good resistance to shear failure.

Significant progress is still called for to improve evenness and to achieve better design of joints, which this site has shown to be necessary in the case of a structure based on the California method.

As concerns noise, the question has been dealt with in the design of porous cement concrete pavements for the following reasons:

1. Among the road generated disturbances, noise is the one most directly felt and perceived by all users and populations living near or far from the road. Conventional solutions using noise barriers or building facade protection have their limits. The focus must also be turned more to the generation and absorption of noise at its source because the role of rolling noise at the tire-pavement contact point is becoming predominant in relation to other noise generation factors (engine noise, mechanical noise, and so on). This trend is accentuated as automakers continue to progress in vehicle and tire design, and as this progress continues to be embodied in new car models and safety campaigns urging users to adopt more moderate driving patterns begin to bear fruit.
2. Theoretical studies for modelling the acoustic absorption phenomenon, have demonstrated the potential of thick porous layers (15)(16)(17) and have shown that:
 1. Noise absorption, very well confined to a narrow frequency range in the case of thin surfacings, exhibits an increased absorption bandwidth as the thickness of the porous materials increases. Figure 8 shows the increase in the number of absorption peaks as thickness increases for a given porous material.
 2. All the peaks join to form a homogeneous absorption layer for a thickness of the order of 50 to 60 cm. Beyond that, there is no further gain. These thicknesses correspond precisely to the orders of magnitude of the thicknesses of medium or heavy traffic pavements. This limit is called the "acoustic superthickness".
 3. Closer examination of the acoustic gain based upon a value analysis approach, as well as the refinement of models following initial field tests, have made it possible to show that over 80% of the absorption gain is provided by one-third of the superthickness, or by 15 to 20 cm of porous material (Figure 9).

Thus, a synthesis of the knowledge acquired to date reveals four main conclusions (18):

1. The optimum potential acoustic gain, from the practical and economic standpoint, corresponds to porous pavement layers of the order of 15 to 20 cm thick. There is also another good thickness, of about 8-10 cm, but this optimum is not stable (rapid drop in absorption if these values are departed from).
2. The useful porosity of the materials is an essential criterion. About 20% of communicating voids would appear to be a minimum; some designs try to achieve 25 or even 30%.
3. Interfaces between layers are highly limiting constructional arrangements in terms of sound wave propagation. The optimum thickness of 15-20 cm should be provided in a single layer to the extent possible.
4. Regular maintenance with cleaning-flushing operations is essential. Progress made in equipment design, in both technical and economic terms, are essential factors for the future and the large-scale development of porous structures. Because of rheological properties, the voids texture should be expected to remain constant with time, thereby facilitating the control of cleaning operations.

Porous cement concrete structures offer advantages aimed particularly at meeting a majority of these objectives (usual application thicknesses, porosity, absence of interface in the acoustically affected zone, voids not varying after hardening owing to rheological properties). Hence, after initial full-scale experimentation conducted near Lyons to validate the superthickness concept (Toussieu site), a second site embodying all the life-size urban constraints was completed in Paris (Avenue de la porte de Vitry).

Let us describe briefly the basic phases and information they provided.

THE TOUSSIEU SITE (7) (19).

The Toussieu site is a road handling light traffic, on which four test sections of thick porous structures of about one hundred meters each were set up. Three structures consisted of multilayer bitumen-treated bases with a bituminous mix wearing course over total thicknesses of 40 to 52 cm. The fourth was a two-layer structure in porous concrete with a total thickness of 40 cm (32 cm + 8 cm on surface). The typical cross-section of the concrete structure is shown in Figure 10.

The following clarifications are called for:

1. From the viewpoint of general design and the architecture of the layers and the roadside arrangements, all precautions were taken to control the water cycle: care given to the levelling of the roadbed after cleaning of poor zones; waterproofing layers in 0/10 bituminous concrete with high bitumen content (thickness of 4 cm); shoulder structure in 20/40 porous untreated granular material partially crushed and covered with a geotextile fabric performing a separating function with the 0/2 granular material used for the shoulder surfacing.
2. From the viewpoint of structural design, the approach was based on an analogy with design calculations customarily used for cement-treated bases and lean concrete on traffic class T2 (150 to 300 commercial vehicles per day on most heavily loaded lane) pavements and a service life of 20 years.
3. The mix designs of the concrete used are the following:

32 cm base courses - Gap-graded 0/20 concrete			
26.3% porosity - 28-day bending strength: 2.10 MPa			
- Semi-crushed 10/20 chippings	1565	kg	
- Rolled 0/15 sand	50	kg	
- Limestone filler	50	kg	
- Acrylic fibers	0.9	kg	
- CPJ45R cement	220	kg	
- Water	70	l	
8 cm wearing courses - 0/10 cement concrete			
25% porosity - 28-day bending strength: 3.45 MPa			
- Crushed 6/10 chippings	1540	kg	
- Limestone filler	50	kg	
- Acrylic fibers	0.9	kg	
- CPA55R cement	300	kg	
- Water	70	l	
- Durciplast additive	3.5	l	

4. Placement was carried out as follows:

For the base course, using a CMI SF 250 stringline guided slipform paver, without internal vibration and with a screed equipped with three electric vibrating pots. This method turned out to be satisfactory, except for some edge sinking behind the machine, which was working at the limit of its possibilities in terms of thickness (Figure 11).

Compacting is finished with a small vibrating roller.

For the wearing course placed with the slipform paver mentioned above, but this placement encountered many difficulties relative to the design, workability of materials, homogeneity of the fibers in the materials, equipment failure extending significantly the completion time, etc.

The scabbing of aggregates observed made it necessary to re-do this layer after planing. The mix design was modified: incorporation of 0/2 crushed sand (60kg); change of nature and proportioning of cement (360kg of CPJ 45 R); discontinued use of fibers.

The modifications required for this reworking (planing, cleaning, etc.) made it possible to obtain a stable porous material with correct intrinsic properties, as shown by the results of the examination of this pavement (Figure 12). However, evenness was found to be unsatisfactory: the cyclic evenness defect of 4 to 5 meter wavelength did not allow this experimentation to be pursued following the initial results of mechanical and acoustic tests. On the latter point, in spite of the evenness defects and the effects of reworking, acoustic results of 75dB were obtained (max. Lp level), measured while passing according to the French-German method, representing a value comparable to the average of porous bituminous mixes used up to that time (75.3dBA).

Assessment

In spite of the difficulties mentioned with regard to the placement, emphasis must be placed on the positive nature of this experimentation from several viewpoints:

- Particularly innovative nature of the first-ever placement of a two-layer structure of large thickness in porous material.
- Very positive results on base course porous concrete: excellent results with regard to the traffic function: carrying capacity, strength, compliance with thickness, bonding of layers, drainability.
- Obtaining first valuable information for pavement mix design (need for a minimum of sand, for example) and execution (organization; limit of equipment). The completion of the thin bonded surfacing on Rue Léon Bollée in Paris mentioned earlier demonstrated shortly afterward that it was possible to obtain such a surfacing with results in keeping with objectives.
- Interesting positioning from the economic standpoint for this type of structure with small number of layers in relation to multilayer structures of the same thickness.

AVENUE DE LA PORTE DE VITRY SITE IN PARIS.

Within the city of Paris, there are about 1500km of roads and streets generally broken down into four families from the viewpoint of their building conditions:

- light traffic roads (local traffic)
- normal traffic roads (main traffic, boulevard)
- heavily travelled roads (Boulevard des Maréchaux, highly travelled bus lanes)
- exceptional strategic roads (Paris ringroad, riverside drives along the Seine, etc.).

The bases of Paris roads are to a great extent in cement concrete (thickness of 20cm)(20), unsurfaced on about 150km (wearing concrete), and paved with setts, asphalt or bituminous mixes in the remaining cases. Thus, 500km of roads are covered with mosaic setts on a sand bed and concrete slab (typical structure, Figure 13).

With a view to reducing disturbances, the Directorate of Roads endeavors, whenever possible, considering the built-up areas, to resurface or transform the sett-stone structures.

Thus, full-scale trials were carried out at Avenue de la Porte de Vitry on the effectiveness of a structure in which the concrete sett and its sand bed were replaced by a porous cement concrete surfacing bonded on the existing concrete base.

This site enabled us, for the first time with a thick porous structure, to really emulate an urban situation with its constraints and its requirements relative to deadlines, operations, safety, coordination, networks, street appurtenances, cleanliness and minimum disturbance in terms of space and duration of the works for motorists and the local population. The chosen street exhibited all these constraints: rapid transit bus terminal to be moved during the construction period, not permitting any overrunning of deadlines, and intense bus traffic 48 hours after the placement of the porous concrete; work under traffic in roadway halves; presence of manholes, hydrants, various kinds subsoil occupation, etc.

The typical structure was composed of:

- 16 cm of gap-graded 0/10 surfacing concrete
- 22 cm of base concrete (reconstructed on this section, exceptionally)
- bearing subgrade.

Owing to the level of loading from buses, it was essential to obtain excellent bonding between the base concrete and the surfacing concrete.

The objectives to be reached in order to fulfill the noise absorption function as well as the traffic function calling for opening to bus traffic within 48 hours after placement were:

- Open porosity: 20% maximum
- Strength: 48-hour compressive strength ≥ 15 MPa
28-day bending strength ≥ 3.5 MPa

To meet this challenge, many particularly careful studies were required in terms of mix design elements. (Table 1)

- 6/10 porphyry chips	1360 kg/m ³
- 0/5 river sand	95 kg/m ³
- 0/0.5 fine sand	25 kg/m ³
- CPJ HPR FS (*) cement	400 kg/m ³
- Durciplast additive, 1.5% cement	6 kg/m ³
- Water	100 liters/m ³

(*) Clinker cement containing about 8% silica fumes introduced during manufacture.

COMPLETION OF EXPERIMENTAL WORKSITE

The urban requirements relative to availability and operations on this avenue called for the completion of the works under traffic, in roadway halves within two weeks from April 7 to 22, 1992 — representing one week to the day between the excavation work and the opening of the porous concrete surface to traffic.

The typical organization was the following:

Day 1	Marking, excavation and compacting of subgrade
Day 2	Placement of base concrete (22cm), first strip
Day 3	Placement of base concrete (22cm), second strip
Day 4	Completion of two strips of porous concrete & surfacing
Day 4 & 5	Sawing of porous surfacing concrete
Day 5 & 6	Drying and hardening of concrete
Day 7	Opening to bus and general traffic

The organizational requirements in a dense urban setting did not make it possible to make full use of the placement suitability test carried out a few days before the start of the works. The specimen construction methods did not allow the reproduction of what actually occurs in the structure behind the placement equipment: paver and compactors.

Thus, the first porous concrete strips, compacted very tightly by means of a 10-ton smooth double-roller machine to ensure cohesion of the surface mortar bridges in order to resist surface scabbing after 48 hours were found to be overcompacted with core-sample porosities of the order of 10% in

the most favorable case, certain bridges being practically completely closed.

A correction was thus made for the two strips of the other direction of traffic, with much lighter compacting since the 10-ton compactor was replaced by a 2.3-ton compactor, to compact the bridge on the curb side, the full slab being compacted by an 0.7-ton double roller. Porosities were thus gradually increased from 13 to 15% on strip 3 and 19 to 21% on strip 4, corresponding to the sought objective.

The photographs of Figures 14 to 19 illustrate the most significant points of the work, as well as the appearance of some core samples taken three months after opening to traffic.

Results concerning the traffic function:

On opening to traffic, the results were globally satisfactory within the context of urban roadways:

- Mechanically satisfactory functioning: compliance with theoretical thicknesses, good bonding of layers, satisfactory concrete strength (porous concrete with 3-day compressive strength of 16MPa and 21% porosity; 28-day bending strength of 4MPa).
- Correct drainability: 0.89m/s percolation rate on average, however with a fairly wide measurement range.
- Correct visual surface characteristics, except for some very early-age scabbing at the start of the works, as well as good texture from the skid-resistance viewpoint. Evenness is considered to be acceptable for an urban road, but would be regarded as insufficient and requiring improvement in the case of larger radial facilities.

Of course, as in any porous surfacing technique, the observation of surface clogging-unclogging processes must be followed very attentively and a very detailed investigation program devoted to it, using physical indicators (acoustic permeability before and after passage of flushing machines).

After 3 months of service, it can already be observed that according to core samples taken in the pavement at this age clogging is located very close to the surface, suggesting rather good potential effectiveness of the specialized machines.

Results concerning the acoustic function.

In this respect also, the urban situation has greatly affected evaluation methods for determining results. It was hence not possible to apply current methods used on fluid roads for measuring the passage of vehicles and hence to position this project according to the criterion of maximum noise level (L_p max) used in the French-German method.

Further, the objective of the road manager is clearly defined: what is important to him is lowering the noise pollution affecting the population, which in the current state of our knowledge and regulations in France is evaluated on the basis of the Leq 8h 20h criterion (average equivalent noise level between 8a.m. and 8p.m.). This indicator includes all noise in the surroundings of the street and not only the rolling noise from vehicles, the latter component having been determined by noise measurements in the immediate vicinity of the tires (front and rear) on a specially equipped vehicle.

The most significant results are the following:

- Overall noise level: Leq 8h 20h

The gain of 4dBA in Leq 8h 20 h is significant. It should however be pointed out that the initial surfacing composed of natural sett-stones was particularly poor from the noise standpoint.

On the other hand, regarding this result, it should be noted that:

- only half of the surface actually corresponds to an acoustically effective thick porous structure (communicating voids percentage of 15 to 20%)
- the speed limits in town, and the road operating conditions with three-colored traffic light intersections on one of the strategic thoroughfares of Paris and the visually and acoustically perceptible presence of the Paris ringroad, limiting the contribution of rolling noise in relation to all the other noises, and engine noise in particular. The presence of commercial vehicles further accentuates this tendency.

Thus, as an example, assuming that the overall noise comes half from engines and half from rolling and that engine noise is unchanged after the works (a likely assumption, examining the histograms of speeds observed before and after works), this would mean that the theoretical gain in terms of rolling noise would be over 10dBA.

	Before works	After works	Gain after/ before works
Order of magnitude of Engine noise Contribution	~ 72 dBA	~ 71dBA	/
Order of magnitude of Rolling noise Contribution	~ 72 dBA	~ 62 dBA	~ 10 dBA
TOTAL	~ 75 dBA	~ 71 dBA	~ 4 dBA

Note: sound level summing rules

If the sound levels L_1 and L_2 of two noise sources working simultaneously are calculated at any point, the resulting level is equal to the larger of the two levels L_1 and L_2 , increased according to Table 3.

Rolling noise measurement

The measurement system is shown in Figure 21. The two microphones placed 10 cm from the surfacing in front and behind the tires make it possible to quantify the effect of tire-pavement contact noise generating mechanisms at the entrance and exit from the contact zone.

Measurements are carried out continuously under traffic at 50 or 60km/h. They are recorded on an analog magnetic recorder and then extracted on a spectrum analyzer and computer. As an example, Figure 22 shows the rolling noise spectra before and after the works on strips B3 and B4 (noise at entrance to contact zone; speed of 50km/h).

It is observed that, in the zone corresponding to the sensitivity thresholds at maximum frequency for the human ear (1000 to 5000Hz), the differences in noise level before and after vary from 7 to 12dBA depending on the frequency, the gains becoming clearly higher than 10dBA between 2000 and 5000Hz. It is moreover within this frequency band that the absorption effect due to the porous thickness appears most clearly, if one examines the results of the low-porosity strips 1 and 2. Toward 4000-5000Hz, porosity alone contributes 5 to 6dBA. Oblique-incidence absorption layers, established according to impulse methods (French standard NFS31089 relative to the acoustic reception of noise barriers - photo in Figure 23) confirm the maximum absorption of these frequency ranges.

These results therefore all appear to be very encouraging. Significant early-age progress has been observed, to the satisfaction of the highway manager and neighboring populations. Much greater improvement potentials are still objectively possible on sites of the fluid urban thoroughfare type by more complete control, over the entire surface, of the expected communicating voids percentage, better evenness, further limiting the generation of noise in relation to the old pavement, closer examination of placement methods to achieve an optimized texture (aggregates lying in the direction of approach of tires, etc.).

GENERAL ASSESSMENT AND CONCLUSIONS.

The importance gradually being granted to this "multifunction" pavement research allowing better osmosis between roads and streets, on the one hand, and the environment, on the other, is justified by the considerable stakes involved, with a duty to succeed as regards highway infrastructure decision-makers and professionals, significant data already available on the subject (theoretical studies, experimental projects, publications), and the very encouraging preliminary results obtained to date, even if much still remains to be done.

Porous cement concrete surfacings have valuable advantages, but a certain number of points still must be worked out in order to make them completely operational.

Today, what is important is having succeeded with a few operations in demonstrating that it is possible to complete such structures with 15-16cm of single-layer porous surfacing meeting the objectives of contracting agencies within the severe conditions of a dense urban site.

Placement is at the heart of the developments in this technique. A wider range of placement equipment (for example, paver with high compacting power), other spreading technologies (vibration controlled from the bottom of the layer, etc.) must be implemented on large-scale sites making it possible to progress significantly with regard to evenness. Rigorous site preparation and organization (manufacturing and placement suitability testing and constant monitoring should make it possible without major difficulty to obtain voids percentages of about 20% (advantage of gammadensimeter type equipment).

Structural properties appear to be excellent. On all the sites, the various "traffic" function indicators are very satisfactory, except as concerns evenness.

The resources to be devoted to research and experimentation in the area of porous concrete should also take into account largely the fast progress and very interesting results obtained with other techniques, and free-draining bituminous mixes in particular. The proper control of their texture and their evenness, and attempts to obtain thicknesses of up to 10cm by seeking to limit the post-compacting phenomenon, are as many positive stimuli to researchers, practicing engineers and other players in the cement concrete road area, with the possibility of offering as quickly as possible better roads and streets contributing actively to the reduction of disturbances, pollution and risks in general for urban populations.

As is always the case for the types of experimentation described in this paper, such issues call for new forms of organization within research and development, in which the public sector (national and local authorities, technical networks) and the private sector (contractors, manufacturers' associations, material and equipment suppliers) bring together their intellectual and financial strengths.

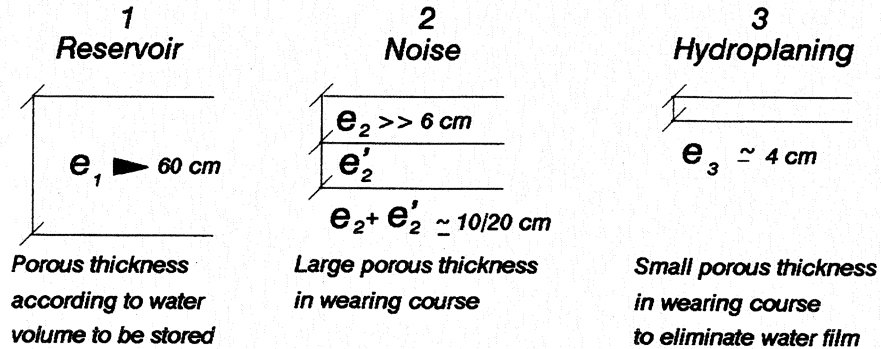
Each technique must be able to make the best of its advantages - and there are potentially many in this case for the concrete structure - and limit its weaknesses so as to give contracting authorities real technical and economic options.

Finally, in every case, and this is specific neither to porous concrete structures nor to other porous or free-draining materials, whether treated or untreated, the question of preventive maintenance is of primary importance, with its aspects of equipment, organization and budgets. These research and development aspects are also to be given priority, and it is conceivable that the technical and economic progress achieved in this area (effective equipment suited to urban surfaces) will have a direct effect on the operational appropriation of thick or semi-thick porous structures by road designers and operators.

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POROUS STRUCTURES OBJECTIVES , PRINCIPLES



- 1 ,2 ,3 ---> Porosity = communicating voids
- 1 ,3 ---> Permeability
- 2 ---> Acoustic absorption = complex phenomenon

Figure 1

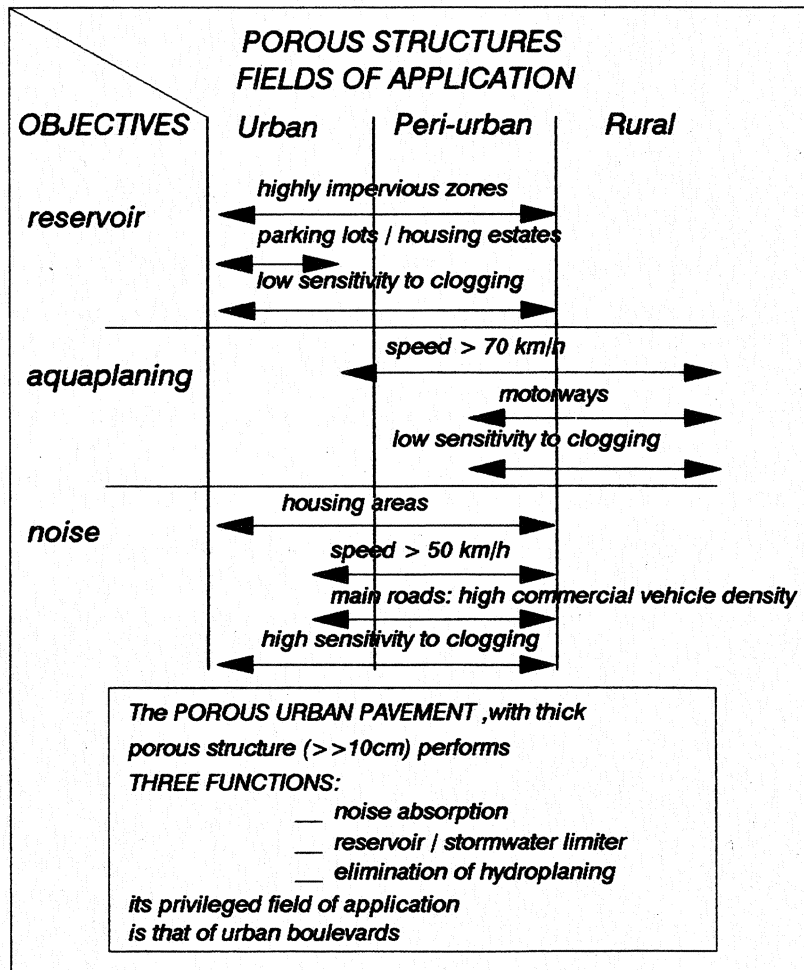


Figure 2

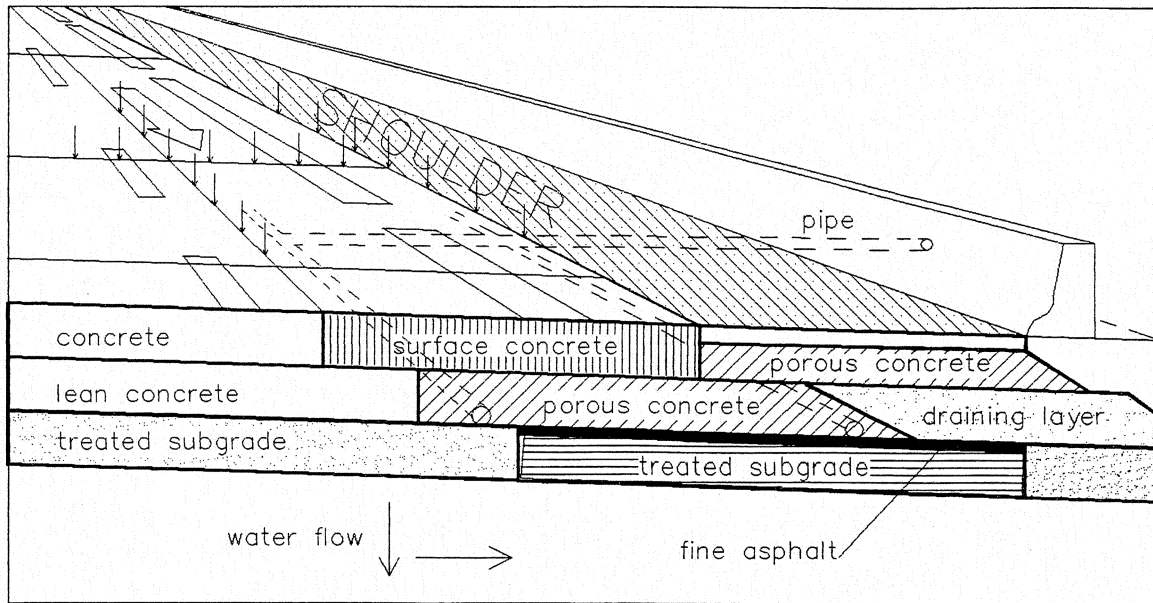


Figure 3: Example of use of porous concrete in base under slab of concrete pavement: Typical cross-section of Autoroute (freeway) A1 in the Greater Paris region (Roissy-La Francilienne section), one of the most heavily travelled in France. Date: 1988.

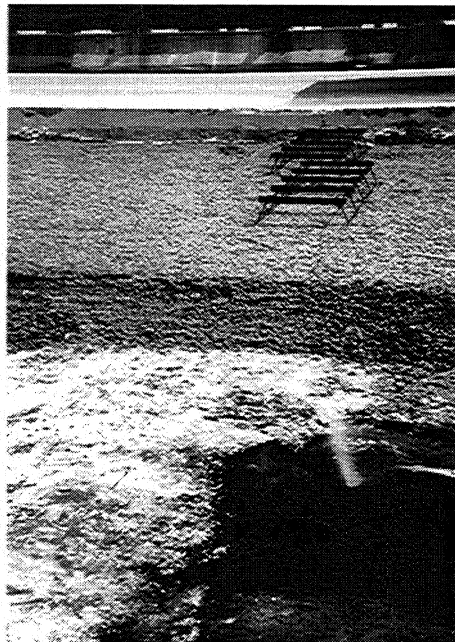


Figure 4: Autoroute A1. Widening of 1988. Appearance of porous concrete base and placing of dowels on baskets before completing the surfacing concrete.

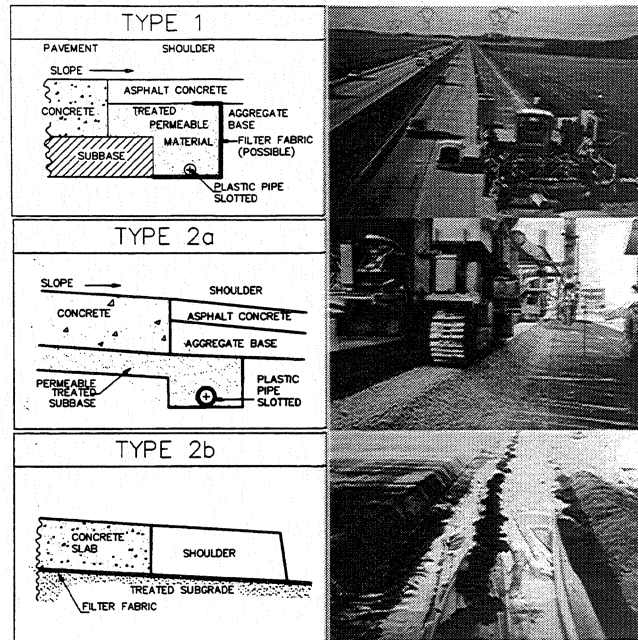


Figure 5: Summary of constructional arrangements advised in PIARC Recommendation for heavy or medium traffic concrete pavement interface drainage. Porous concrete is used widely in two of them: type I and type IIa.

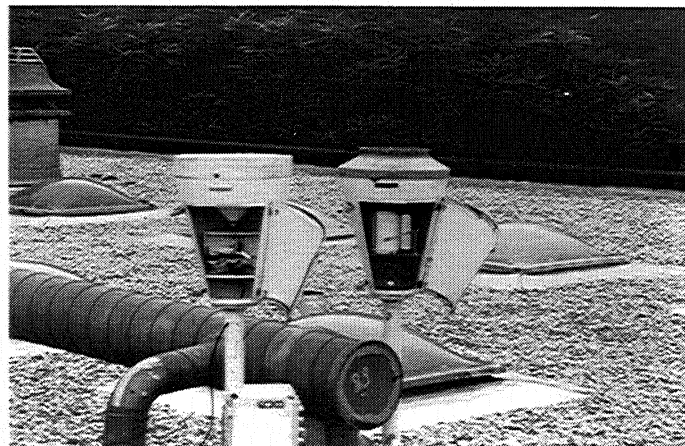
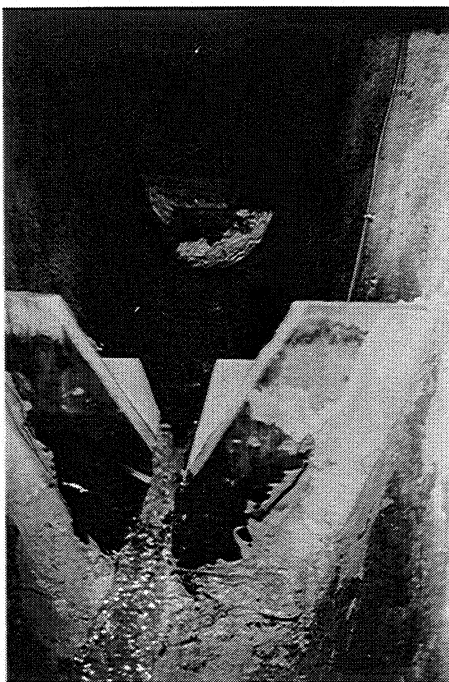
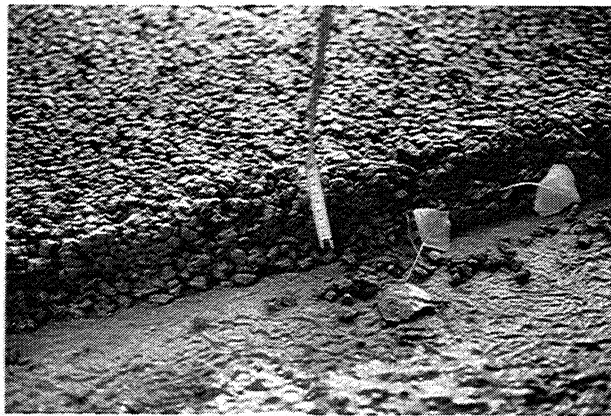


Figure 6: Element of hydraulic measurement instrumentation for a cement concrete porous structure: stabilization baffles and continuous level measurement device in the drainage collector (Figure 6A) and rainfall instrumentation placed near the structure (Figure 6B).



7 - A. Protection of fresh concrete with metallized polyethylene sheet: one of the key points for proper bonding, eliminating the temperature gradient.



7 - B. Porous cement concrete pavement; detailed view.



7 - C. Porous cement concrete pavement; general view.

Figure 7: Rue Léon Bollée in Paris: placement of thin layer of porous concrete (6cm) bonded to the existing concrete pavement.

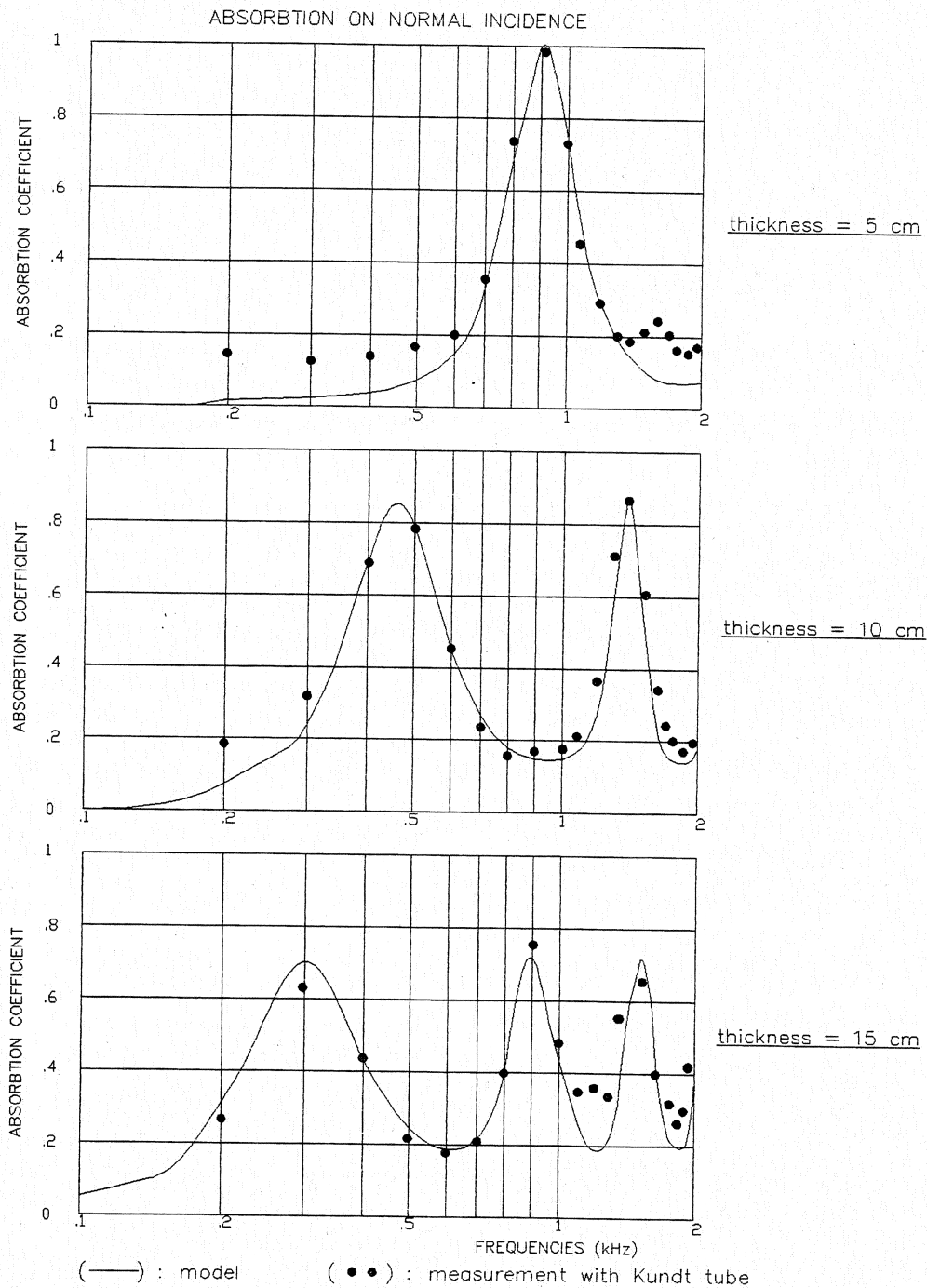


Figure 8: Modelling of porous structures. Evolution of spectrum of absorption coefficient as a function of thickness. Model-thickness comparison.

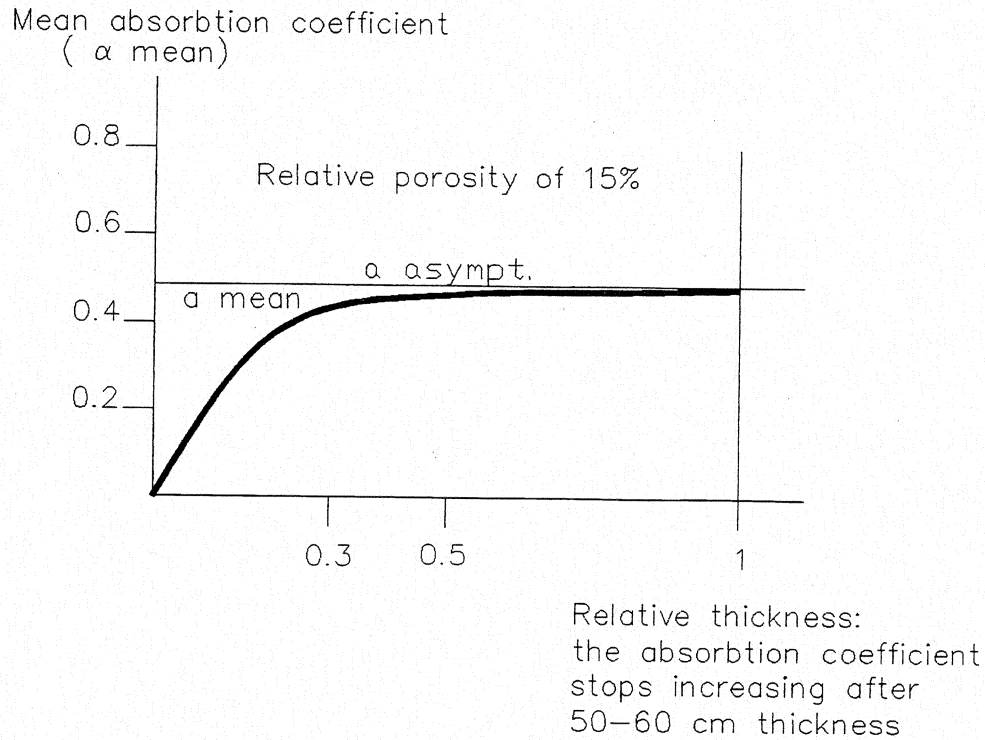


Figure 9: Optimization of the acoustically useful thickness in a porous structure: mean absorption coefficient as a function of relative thickness. About 90% of the absorption is reached on one-third of the effective maximum theoretical thickness (superthickness), or 15 to 20cm of porous material.

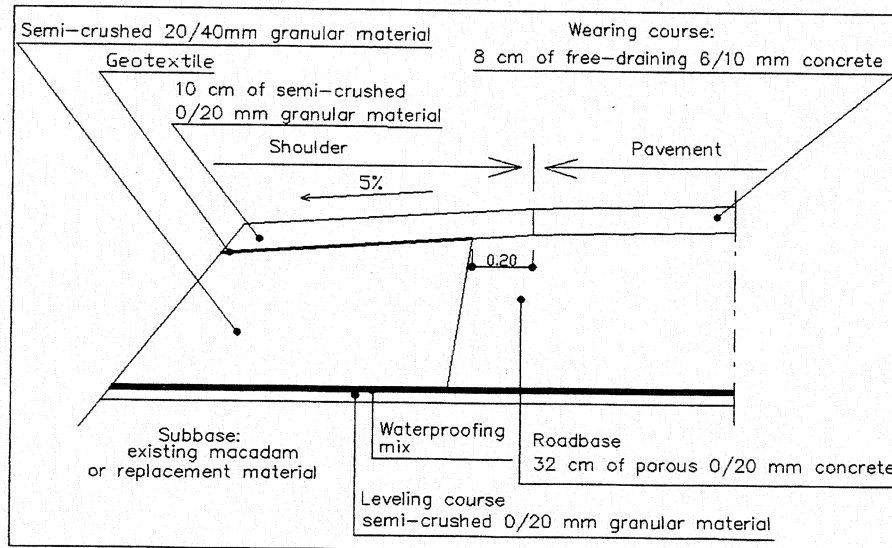
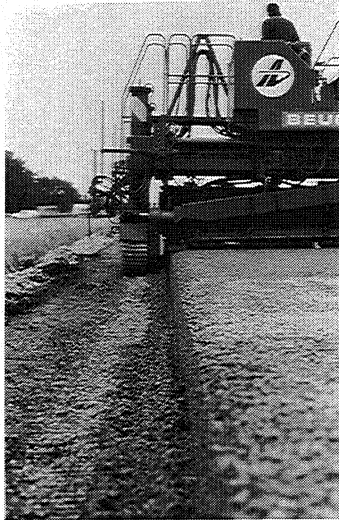
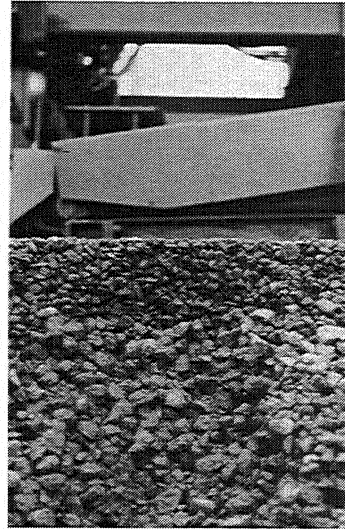


Figure 10: Toussieu site (Lyons). First urban pavements in porous cement concrete completed in France. Typical cross-section of structure and roadside arrangements.



11.A



11.B

Figure 11: Urban porous pavement of Toussieu (Lyons) in porous cement concrete. Placement of 32cm thick porous concrete base (11.A). Spreading of porous concrete and surfacing with slipform paver to form a new two-layer porous concrete structure (11.B).

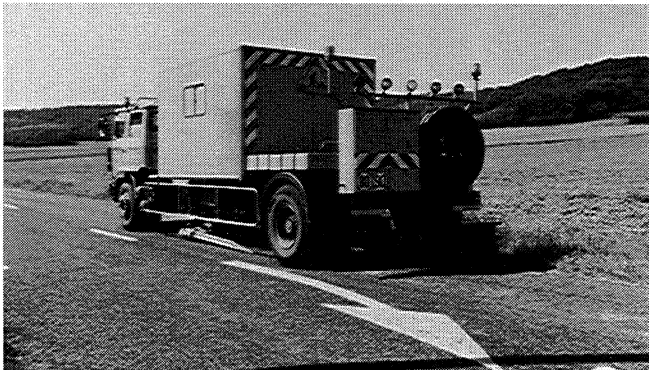
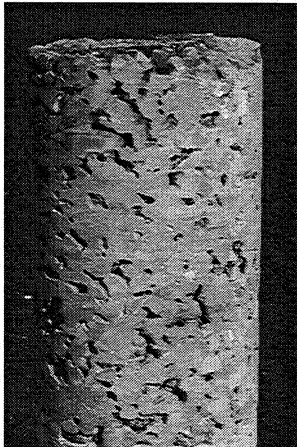
QUALITY	PARAMETER MEASURED	RESULTS	REFERENCE THRESHOLDS
CARRYING CAPACITY		6 to 10/100 mm	good capacity if <20/100 mm
	DEFLECTION		
THICKNESS			
	LCPC radar + core sampling	40 cm	satisfactory

Figure 12: Urban pavements in porous cement concrete Toussieu site (EVALUATION OF TRAFFIC FUNCTION) First year

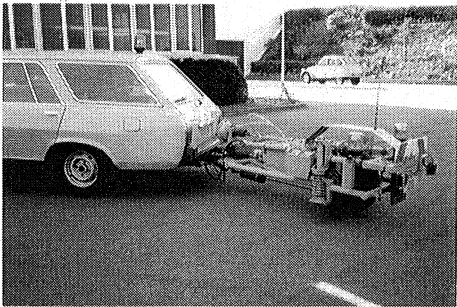
QUALITY

PARAMETER MEASURED

RESULTS

REFERENCE
THRESHOLDS

SKID RESISTANCE

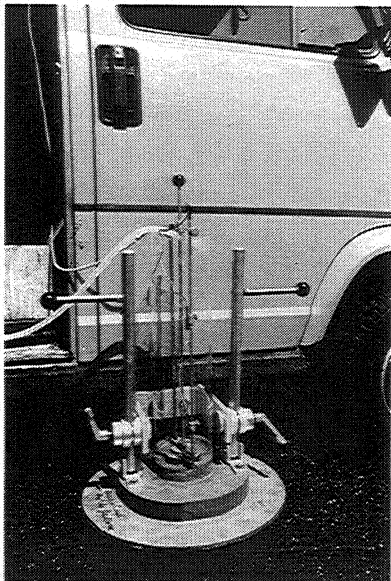


0.35 at 90 km/h

80% of French
pavement between
0.15 and 0.40

Sideways force coefficient

DRAINABILITY

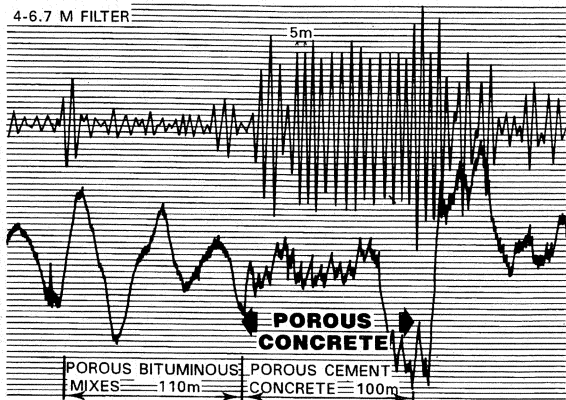


1.32 cm/s

porous pavement
if $v > 0.70$ cm/s

Porous pavement Field permeameter
(average percolation rate)

EVENNESS



cyclic defect of
wavelength

defective

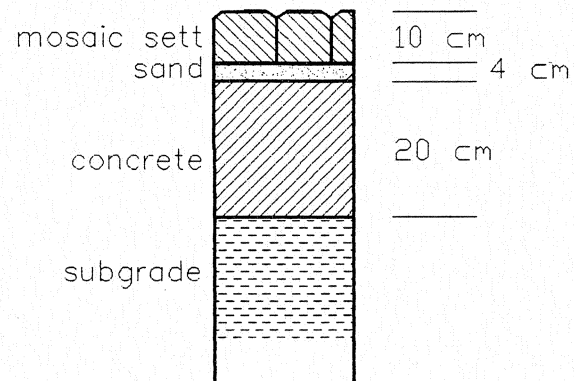
Longitudinal profile analyzer

Figure 12: Urban pavements in porous cement concrete
(Continued)

(2) Mosaic setts on concrete sub-base.

Typical structure

example : rue Lepic



Advantage: improved surface condition for user compared with the sample setts used formerly (50% of Paris pavements in 1926)

Extension: one-third of inner Paris including sample setts.

Figure 13: Typical structures of old Paris roads built between 1950 and 1970: Pavement in mosaic setts on a concrete base.



Figure 14: After excavation, placement of base concrete with slipform paver.

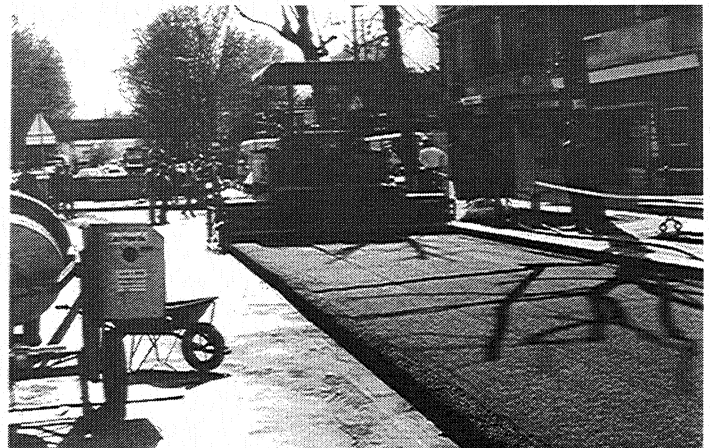


Figure 15: Placement of porous surfacing concrete (16cm) with paver.

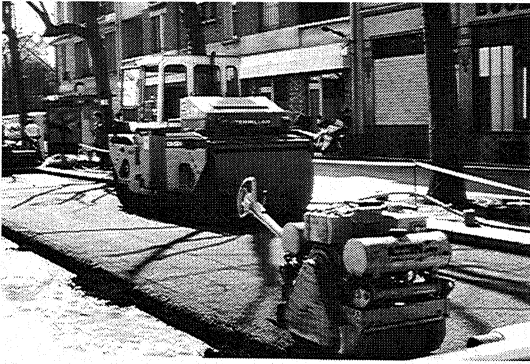


Figure 16: Heavy compacting of first strips.
10-ton compactor.



Figure 17: Modification of equipment, using a lighter compactor.



Figure 18: Appearance of site after opening to traffic

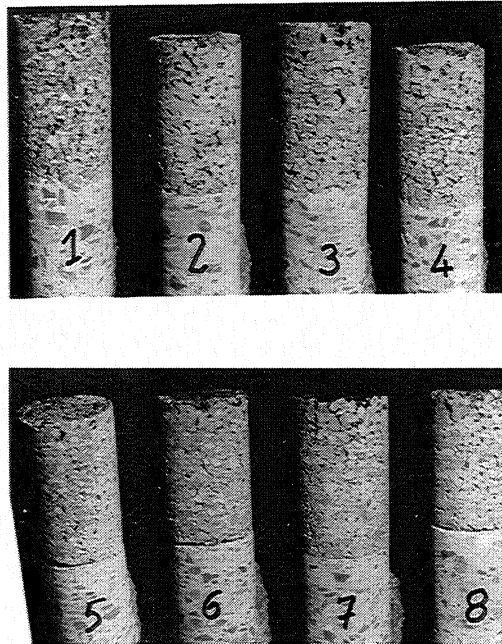


Figure 19: Appearance of core samples taken in strips 3 and 4, making it possible to:

1. Check compliance with the 16-cm thickness
2. Measure the communicating voids ratio (open porosity)
3. Check the bonding between the base concrete and the porous surfacing concrete
4. Measure the tortuosity of the voids with the scanner
5. Measure the acoustic absorption coefficients with the Kundt tube

The positive point of this project is that, faced with start-up difficulties relative to the control of voids (phenomena underestimated before the start of the works), it was possible to take measures in terms of both equipment and evaluation procedures in order to obtain a strip meeting our objectives. The overall judgement made relative to this experimental site must consequently always allow for this with regard to both the traffic function and the acoustic function. It will be considered globally, for the latter, that 50% of the surface provides acoustic absorption according to the functioning mode of thick or semi-thick porous structures which, based upon some results developed below, confirms the excellent potential of this technique.



Figure 20: Positioning of measurement point for measuring the Leq 8h 20h. Acoustic measurements on building facades



Figure 21: Rolling noise measurement: positioning of microphones in front and rear position in relation to the tire-pavement contact area. Height: 10cm from measured surfacing.

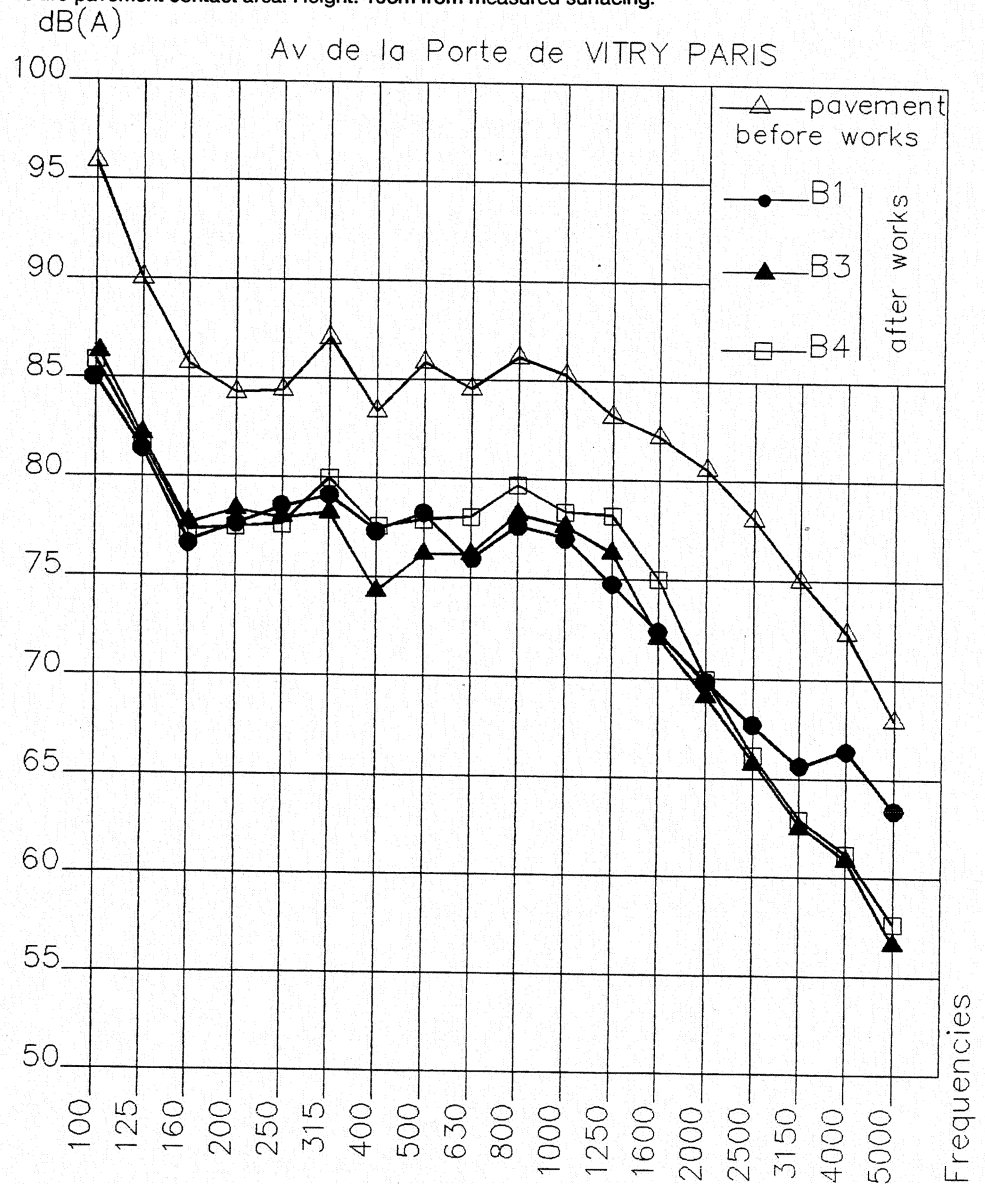


Figure 22: Rolling noise spectrum before and after works on porous strips B3 and B4 and on low porosity strip B1.



Figure 23: Measurement of absorption of porous surface by means of LCPC impulse method (French standard NF S 31089).

Table 1:

IREX PROJECT – POROUS CONCRETE

Prior study of experimental site of Avenue de la Porte de Vitry in Paris – Selection of three best mix designs, mechanically and acoustically.

		13	14	15
Chips	6/10	1360	1360	1360
Sand	0/5	120	120	120
Cement	CPA HP CORMEILLES CPA 55 COUVROT	380	400	380
SIKACRETE	HD	30		
CIMFLUID	232		8	
CIMLATEX			24	
Laudrun silica fumes			38	
LOMAR D fluidizer				6.8
Water		100	82	80
Slump. Observations	1 cm	1 cm	1 cm	
Theoretical density	1.990	1.994	1.985	
Density of fresh concrete		1.935 1.937 1.915	1.953 1.943 1.948	1.962 1.928 1.942
AVERAGE		<u>1.929</u>	<u>1.948</u>	<u>1.946</u>
Open porosity	%	19.9 19.6 20.0	19.2 19.8 19.6	20.0 21.9 20.8
AVERAGE		<u>19.8</u>	<u>19.5</u>	<u>20.9</u>
Strength:	MPa			
Compressive	2-day 7-day 28-day	14.0 15.8 18.2	14.8 15.5 16.9	17.7 17.5 19.6
Bending	7-day 28-day	3.52 4.21	3.56 3.83	4.38 4.42